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NOLTR 67-17

COMPARISON OF THE UNDERWATER POWER OF EXPLOSIVES IN SMALL CHARGES
XI. FURTHER DEVELOPMENT OF TEST PROCEDURES

3 MARCH 1967

NOL

UNITED STATES NAVAL ORDNANCE LABORATORY, WHITE OAK, MARYLAND

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COMPARISON OF THE UNDERWATER POWER OF EXPLOSIVES IN SMALL CHARGES

XI. FURTHER DEVELOPMENT OF TEST PROCEDURES

by

Thomas B. Heathcote
C. R. Niffenegger

ABSTRACT: Four explosives pressed to three densities and boostered with truncated cones of pressed pentolite were used to continue a study to determine optimum density and boostering for underwater evaluation of small charges. The study showed that HBX-1, TNT/Al/Wax (55/40/5), and ammonium perchlorate/TNT/Al (45/20/35) gave a substantially greater output at 85-90% Theoretical Maximum Density than previously obtained. Pentolite charges pressed to three densities gave the same results as cast charges; it is recommended as a standard. The procedures used here are recommended for small charges.

UNDERWATER EXPLOSIONS DIVISION
EXPLOSIONS RESEARCH DEPARTMENT
U. S. NAVAL ORDNANCE LABORATORY
WHITE OAK, SILVER SPRING, MARYLAND

NOLTR 67-17 3 March 1967

COMPARISON OF THE UNDERWATER POWER OF EXPLOSIVES IN SMALL CHARGES.
XI. FURTHER DEVELOPMENT OF TEST PROCEDURES

The work described in this report is part of the Naval Ordnance Laboratory's continuing program of investigation of the underwater performance of explosive mixtures, under ORD Task No. ORD-033-211/092-1/F008-08-11, Work Unit c. This study was made as a continuation of the effort to find a better charge preparation technique and a better boostering system, so that inexpensive, rapid, small charge tests would assuredly give the same output per unit weight as large charges.

E. F. SCHREITER
Captain, USN
Commander

C. J. ARONSON
By direction

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XI. FURTHER DEVELOPMENT OF TEST PROCEDURES

1. INTRODUCTION

Evaluation of the underwater explosive power of new compositions usually starts with firings of one-pound charges. In these initial tests, measurements are made by diaphragm gages that provide a comparative measure of shock wave energy; and bubble energy is found from bubble periods. It is essential that two conditions be carefully adhered to if such tests are to provide meaningful data: (1) Primary and secondary standard charges must give a consistent output from shot to shot and from test to test. (2) Initiation of experimental compositions should be adequate to ensure that the steady-state reaction (detonation) occurs in the entire charge.

Frequent failure to achieve full underwater power was suggested by an inconsistent output observed for small HBX-1 charges used as secondary standards over a number of years (Ref. a)* and failure of some small charges to scale to large charge values (Ref. b). As a consequence, methods designed to improve the reliability of the underwater tests were recommended (Ref. b). These involved the use of pressed charges of 90-98% Theoretical Maximum Density and full-diameter conical boosters. Tests were conducted to investigate the effects of these changes (Ref. c). The "full potential performance" was realized for HBX-1 charges and for an AP/TNT/Al mixture; however, the data were not adequate to demonstrate a charge size effect for the other mixture tested.

The work reported here was done as a continuation of the work of reference (c). First, the range of pressed charge densities was extended down to 85% TMD to see if there might be an optimum density for the insensitive explosives tested. Second, some additional data for the charge size effect study was obtained with 1-lb charges.

2. EXPERIMENTAL DETAILS

2.1 CHARGES

The same compositions were used for this test as in reference (c). They were pentolite: PETN/TNT (50/50); HBX-1: RDX/TNT/Al/Wax (40/38/17/5), TNT/Al/Wax (55/40/5), and AP**/TNT/Al (45/20/35). Densities of about 85, 90, and 95% theoretical maximum density (TMD) were fired for each charge type.

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* References are listed on page 6.

** ammonium perchlorate

Most of the charges were isostatically pressed by personnel of the Chemical Engineering Division at the Naval Ordnance Laboratory. The charges were right cylinders having length-to-diameter ratios of from 1:1 to 1.?:1. Eight charges of each density were fired; four of each had 30 gm and four had 100 gm boosters consisting of truncated cones of pressed pentolite (Ref. c). Additionally, a limited number of charges had inset cylindrical boosters and a few charges were cast for comparison with previous results. The pressed charges and boosters were waterproofed with a light layer of acrylic spray enamel.

All of the materials for each composition were mixed at one time to achieve uniformity from charge to charge. Most of the charges weighed 454 gm including the pentolite boosters. Pertinent charge data are recorded in Table 1.

Pentolite, PETN/TNT (50/50). In reference (c), four weights of cast pentolite charges were used as the primary standards. Pressed pentolite charges whose densities were between 93% and 96% TMD gave underwater power the same as that for the cast charges; i.e., showing that there was no initiation problem with cast pentolite. Since it appears that other explosives may require lower densities than 95% TMD to produce full underwater power, pressed pentolite charges with densities of 85 and 90% TMD were fired on these tests. Four weights (227, 300, 454, and 600 gm) of pressed pentolite charges of 95% TMD were used as the primary standards. One weight of vacuum cast charges was also fired for comparison with previous results.

HBX-1, RDX/TNT/Al/Wax (40/38/17/5). The results of reference (c) indicated that the apparent chronological decline in the shock wave energy of HBX-1 (Ref. a) was the result of poor initiation and not a decline in the underwater power of HBX-1. Additional tests of charges with lower densities were required to determine this conclusively. Charges were pressed to 85, 90, 95, and 98 percent TMD and boostered with conical pressed pentolite boosters. Four additional charges were pressed to 98% TMD; 30 gm and 100 gm cast cylindrical boosters were used on these charges. Pressed conical boosters of 30 and 100 gm were also used to booster 4 cast charges of HBX-1.

TNT/Al/Wax (55/40/5). Previous underwater experiments with this difficult-to-initiate composition had shown both a booster size effect and failure of 1-lb charges to scale to charges of larger size. In reference (c), it is shown that analogous results were obtained for the 30 and 100 gm boosters, if the boosters were truncated cones of pressed pentolite. However, the shock power remained significantly less than that expected from adequately boostered, larger charges. By including charges pressed to 85, 90, and 95 percent TMD (and with conical boosters), it was hoped that we could determine whether the charges had been inadequately boostered or if this mixture showed a charge-size effect.

AP/TNT/Al (45/20/35). Underwater explosion data obtained in the past for cylindrically boostered 1-lb cast charges of this highly aluminized mixture revealed what was thought to be a charge size effect (Ref. b). Test results reported in reference (c) show that conically boostered charges of this composition pressed to 93% TMD gave an energy output improved to the extent that the existence of a charge size effect was doubtful. It is believed that inadequate initiation was responsible for failure of 1-lb charges to scale to large charge values. Additional charges were fired in the recent program to increase confidence in the results of reference (c). The charges were pressed to 85, 90, and 95 percent TMD and utilized pressed conical boosters. (It should be noted that N126 ammonium perchlorate (average particle size less than 45 micron) was used in charges for these tests. For charges fired earlier (Ref. c), APN119 (200 micron average size) was used.

2.2 EQUIPMENT AND TEST PROCEDURE.

Four charges of each type were fired. All charges were initiated with U. S. Army Engineers Special Electric detonators.

Four diaphragm gages were used on each shot to obtain "relative shock wave energies" (W_{Dd}'s). The charges were suspended centrally in an 8-ft diameter steel ring with the charge and gage orientation being identical to that described in reference (d). Two 1/2-in diameter piezoelectric gages were used to obtain bubble periods from which relative bubble energies (K^3) were calculated. A probe similar to one reported in reference (e) was used to measure the size of the gas bubbles produced by the explosions. The results of these measurements are reported in Appendix A. The shots were fired from the NOL barge at a 9-ft depth in from 18 to 25 ft of water.

3. RESULTS AND DISCUSSION

The relative shock wave and bubble energies were computed from the experimental data on the IBM 7090. All values were obtained relative to pressed pentolite (95% TMD), as outlined in reference (d). Values are shown, on an equal weight basis, in Table 1.

Pentolite Charges. Table 1 shows the results of the tests with cast and pressed pentolite. The W_{Dd}'s for the pressed charges varied from 0.98 to 1.00; the RBE's varied from 0.99 to 1.01. The W_{Dd} for the cast pentolite relative to the pressed standard was 0.99; the RBE was 1.00. These small differences are not statistically significant. Hence, there is no substantial change in pentolite output for charges pressed to densities over a range most likely to be of practical interest in future work and no significant difference between pressed and cast pentolite charges.

As discussed in reference (c), pressed mixtures are recommended for two reasons: (1) pressed charges can be reproduced more reliably than cast, and (2) pressed charges have the advantage of greater shock sensitivity than cast.

HBX-1. The results for the HBX-1 charges are also shown in Table 1. W_{Dd}'s and RBE's for charges pressed to 85 and 90% TMD are in good agreement with the highest existing values for HBX-1 (Ref. f).

The results for the pressed charges with conical boosters are shown in Figure 1 along with the values for pressed charges with cylindrical boosters given in Table 1 and reference (c). It is apparent that the charges with conical boosters gave consistently greater output than those with cylindrical boosters.

The W_{Dd}'s for 85 and 90% TMD are equal, but the RBE's still show a slight increase with decreasing density. Charges with smaller densities (80% and 75% TMD) should be fired to determine if this apparent trend is real.

Analyses of all existing HBX-1 data indicate that inadequate initiation has been the reason for the low values for HBX-1 and that the full underwater power can be obtained by the use of higher porosity (85 to 90% TMD) acceptors boostered with conical pressed pentolite boosters. The best values of W_{Dd} and RBE for HBX-1 are 1.15 and 1.48, respectively.

TNT/Al/Wax (55/40/5). W_{Dd}'s in Table 1 and Figure 2 for a charge density of about 95% TMD essentially duplicate those in reference (c). There is considerable scatter among the RBE's for the charges pressed at 95% TMD. The large variations in the W_{Dd}'s and particularly the RBE indicate that this mixture is very difficult to initiate even in pressed charges.

Values of W_{Dd} and RBE for large charges of this mixture were estimated to be 0.68 and 1.98 respectively. The W_{Dd} for the 85% TMD charges was 0.72 which is slightly above the estimated value. The RBE for the 85% TMD charges is significantly greater than that for the 90% TMD charges, but even so does not reach the estimated value of 1.98. The values obtained for this mixture indicate that it is a very difficult mixture to initiate so there is probably no real charge size effect. Additional charges at 80% and 75% TMD, and possibly smaller values, should be tested to determine whether the large charge values can be duplicated.

AP/TNT/Al (45/20/35). The W_{Dd}'s and RBE's shown in Table 1 and Figure 3 show no density effect for the pressed charges with conical boosters over the range of densities studied. There are no significant differences among the six values obtained on the present tests for either W_{Dd} or RBE.

The W_{Dd}'s obtained on these tests are higher than any observed previously for 1, 10, 30, or 50-lb charges of this mixture (Ref. c). However, the RBE's for the same charges are somewhat lower than those obtained in references (c) and (g). The particle size of the AP in the present series was less than 45 microns, much smaller than that used previously (200 microns). This change appears to have affected the shock sensitivity of this mixture and also resulted in a change in the energy partition.

4. SUMMARY AND CONCLUSIONS

1. Vacuum-cast pentolite and pentolite pressed to 84 and 90% TMD showed no significant differences in W_{Dd} or RBE.

2. HBX-1 pressed to 85 or 90% TMD boostered with pressed conical pentolite boosters gave W_{Dd}'s and RBE's equal to the highest values previously obtained for 1-lb charges. Charges pressed to TMD ≥ 95% gave lower values.

3. Pressed charges of HBX-1 with conical pressed pentolite boosters gave a greater output than with cylindrical pressed pentolite boosters.

4. The more porous (85% TMD) 1-lb charges of TNT/Al/Wax with conical pressed pentolite boosters gave W_{Dd}'s in agreement with the values predicted from large charge results for this mixture. The RBE's, although still considerably lower than estimated for the large charges, were much higher than those obtained on previous 1-lb tests. Figure 2 shows that RBE has not reached a maximum value; W_{Dd} has, or nearly has.

5. W_{Dd}'s and RBE's were independent of porosity (for TMD between 84 and 92%) for the AP/TNT/Al mixture tested. However, there were significant differences between the values reported herein for charges with fine (< 45 micron) AP compared with the coarser (200 micron) AP used previously.

5. RECOMMENDATIONS

1. The first three major recommendations outlined in reference (c) for changing the test procedure for 1-lb charges should be adopted whenever possible. These are: (a) "Use pressed pentolite as the primary standard, (b) "Use pressed pentolite truncated conical boosters, (c) "When possible, in testing new materials, use pressed test charges at two porosities (e.g., 85% and 90% TMD) and examine results for a porosity effect in analogy to the way 30 g and 100 g boosters are used to detect a booster effect."

2. Conduct tests on effect of density at 80% TMD and less for HBX-1 and TNT/Al/Wax (55/40/5).

3. Fire 10-lb (or larger) charges of HBX-1 and TNT/Al/Wax for comparison with the 1-lb results.

4. Conduct tests on effect of particle size on ammonium perchlorate charges.

ACKNOWLEDGEMENT

The authors wish to acknowledge the continued interest shown, many helpful suggestions made, and the review of this report done by Dr. Donna Price of this laboratory.

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TABLE 1

CHARGE DATA AND RESULTS

Explosive	Charge Density (gm/cc)	Percent of TMD[3]	Booster Explosive	Booster Shape	Booster Weight (gms)	Charge Weight[4] (gms)	W_{Dd}(pent)	RBE(pent)
Pressed Pentolite[1]	1.54	90.2	None	None	None	454	1.00	0.99
Pressed Pentolite	1.44	84.2	None	None	None	450	0.98	1.01
Vacuum Cast Pentolite	1.69	98.6	None	None	None	454	0.99	1.00
Pressed HBX-1[2]	1.72	97.7	Pressed Pentolite	Conical	30	454	0.97	1.21
Pressed HBX-1	1.72	97.7	Pressed Pentolite	Conical	100	454	1.05	1.41
Pressed HBX-1	1.69	96.0	Pressed Pentolite	Conical	30	454	1.12	1.47
Pressed HBX-1	1.68	95.5	Pressed Pentolite	Conical	100	454	1.11	1.44
Pressed HBX-1	1.58	89.8	Pressed Pentolite	Conical	30	454	1.15	1.48
Pressed HBX-1	1.60	90.8	Pressed Pentolite	Conical	100	454	1.15	1.44

1/ PETN/TNT; 50/50.

2/ RDX/TNT/Al/Wax; 40/38/17/5.

3/ Theoretical Maximum Density (TMD) for pentolite is 1.71 gm/cc; for HBX-1 1.76 gm/cc.

4/ Charge Weight includes the booster weight.

TABLE 1 (continued)

CHARGE DATA AND RESULTS

Explosive	Charge Density (gm/cc)	Percent of TMD 2/	Booster Explosive	Booster Shape	Booster Weight (gms)	Charge Weight 3/ (gms)	W_{Dd}(pent)	RBE(pent
Pressed HBX-1	1.51	85.8	Pressed Pentolite	Conical	30	454	1.14	1.50
Pressed HBX-1	1.49	84.7	Pressed Pentolite	Conical	100	454	1.15	1.49
Pressed HBX-1	1.71	97.2	Pressed Pentolite	Cylindrical	30	454	0.94	1.21
Pressed HBX-1	1.72	97.7	Pressed Pentolite	Cylindrical	100	454	0.92	1.20
Cast HBX-1	1.72	97.7	Pressed Pentolite	Conical	30	454	1.09	1.50
Cast HBX-1	1.72	97.7	Pressed Pentolite	Conical	100	454	1.11	1.50
Pressed TNT/Al/Wax 1/	1.79	95.2	Pressed Pentolite	Conical	30	454	0.49	0.74
Pressed TNT/Al/Wax	1.79	95.2	Pressed Pentolite	Conical	100	454	0.54	0.83
Pressed TNT/Al/Wax	1.69	89.8	Pressed Pentolite	Conical	30	454	0.70	1.53

1/ TNT/Al/Wax; 55/40/5.

2/ Theoretical Maximum Density (TMD) for TNT/Al/Wax (55/40/5) is 1.88 gm/cc

3/ Charge Weight includes the booster weight.

TABLE 1 (continued)

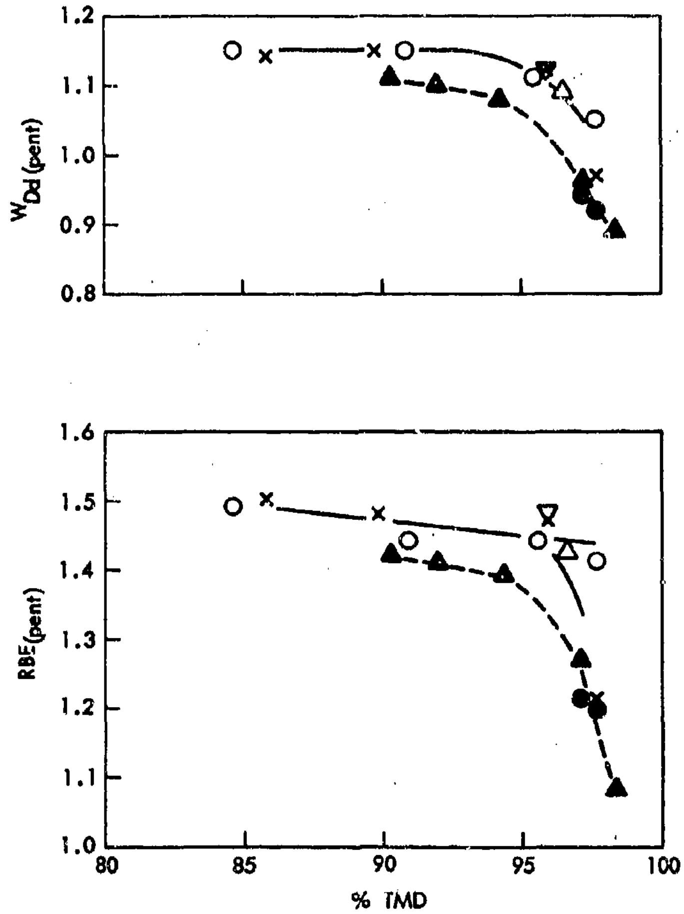
CHARGE DATA AND RESULTS

Explosive	Charge Density (gm/cc)	Percent of TMD[2]	Booster Explosive	Booster Shape	Booster Weight (gms)	Charge Weight[3] (gms)	W_{Dd}(pent)	$RBE_{(pent)}$
Pressed TNT/Al/Wax	1.69	89.8	Pressed Pentolite	Conical	100	454	0.69	1.58
Pressed TNT/Al/Wax	1.60	85.1	Pressed Pentolite	Conical	30	454	0.72	1.71
Pressed TNT/Al/Wax	1.60	85.1	Pressed Pentolite	Conical	100	454	0.72	1.73
Pressed AP/TNT/Al[1]	1.92	92.3	Pressed Pentolite	Conical	30	454	1.21	2.18
Pressed AP/TNT/Al	1.92	92.3	Pressed Pentolite	Conical	100	454	1.25	2.17
Pressed AP/TNT/Al	1.89	90.9	Pressed Pentolite	Conical	30	454	1.23	2.20
Pressed AP/TNT/Al	1.89	90.9	Pressed Pentolite	Conical	100	454	1.23	2.20
Pressed AP/TNT/Al	1.75	84.2	Pressed Pentolite	Conical	30	454	1.22	2.20
Pressed AP/TNT/Al	1.75	84.2	Pressed Pentolite	Conical	100	454	1.19	2.20

1/ Ammonium perchlorate/TNT/Al; 45/20/35.

2/ Theoretical Maximum Density (TMD) for AP/TNT/Al (45/20/35) is 2.08 gm/cc.

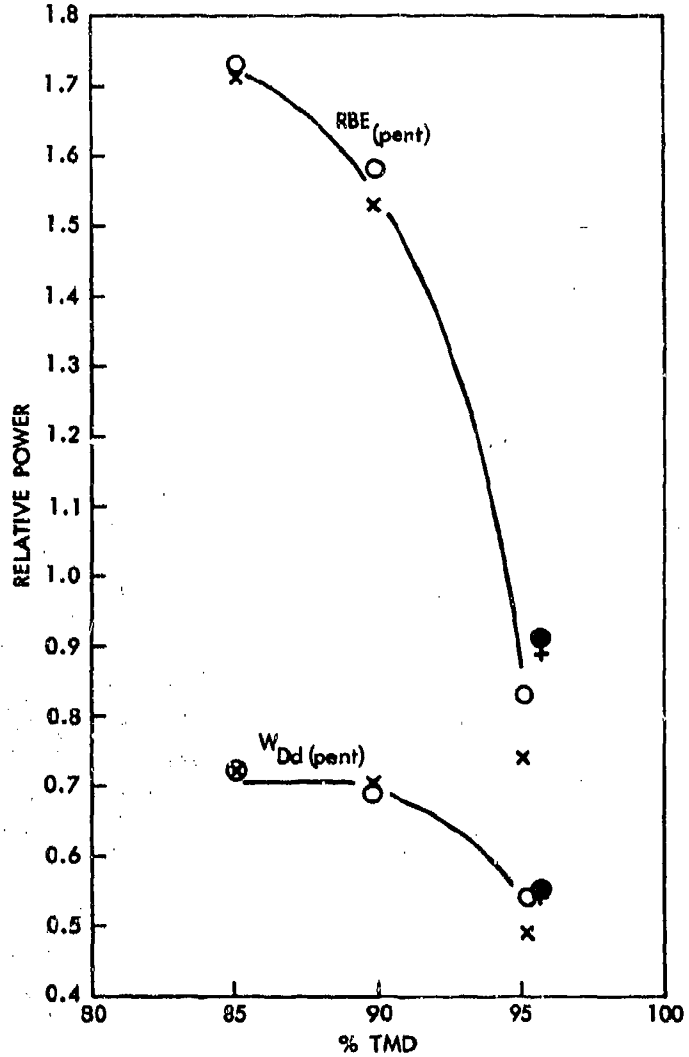
3/ Charge Weight includes the booster weight.



CHARGE PREPARATION

× PRESSED; 30 gm CONICAL BOOSTER; THIS REPORT
△ PRESSED; 30 gm CONICAL BOOSTER; REF (C)
○ PRESSED; 100 gm CONICAL BOOSTER; THIS REPORT
▽ PRESSED; 100 gm CONICAL BOOSTER; REF (C)
● PRESSED; CYLINDRICAL BOOSTER; THIS REPORT
▲ PRESSED; CYLINDRICAL BOOSTER; REF (C)

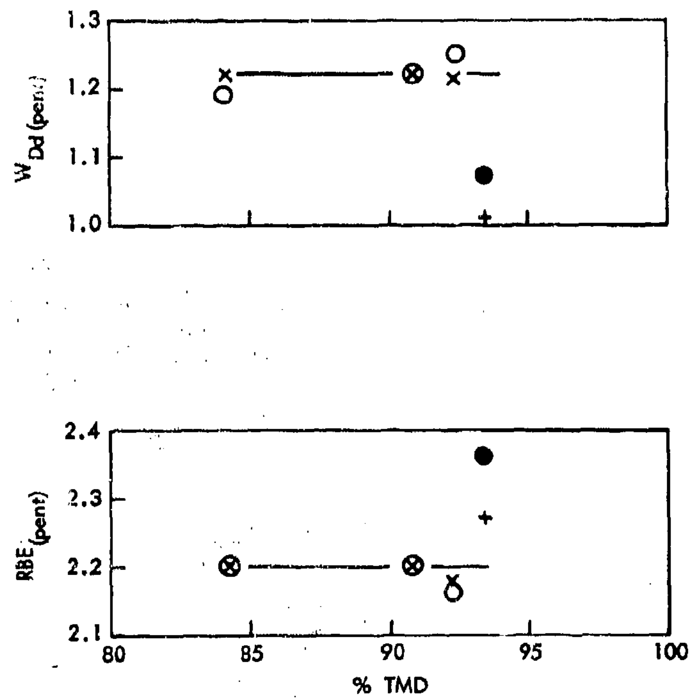
FIG. 1 THE EFFECT OF CHARGE DENSITY ON THE UNDERWATER POWER OF SMALL HBX-1 CYLINDERS



CHARGE PREPARATION

× PRESSED; 30 gm CONICAL BOOSTER; THIS REPORT
○ PRESSED; 100 gm CONICAL BOOSTERS; THIS REPORT
+ PRESSED; 30 gm CONICAL BOOSTER REFERENCE (C)
● PRESSED; 100 gm CONICAL BOOSTER REFERENCE (C)

FIG. 2 THE EFFECT OF CHARGE DENSITY ON THE UNDERWATER POWER OF SMALL CYLINDERS OF TNT/Al/WAX; 55/40/5



CHARGE PREPARATION

× PRESSED; 30gm CONICAL BOOSTER - THIS REPORT
O PRESSED; 100gm CONICAL BOOSTER - THIS REPORT
+ PRESSED; 30gm CONICAL BOOSTER - REFERENCE (C)
● PRESSED; 100gm CONICAL BOOSTER - REFERENCE (C)

FIG. 3 THE EFFECT OF CHARGE DENSITY ON THE UNDERWATER POWER OF SMALL CYLINDERS OF AP/TNT/Al; 45/20/35

APPENDIX A

MEASUREMENT OF MAXIMUM BUBBLE RADIUS

A.1 BACKGROUND

For many years the ratio of the cube of the bubble period coefficients (K) has been used as a measure of the relative bubble energies (RBE) of two explosives. H. G. Snay of this Laboratory has pointed out on several occasions that the relative bubble energy for highly aluminized mixtures should be determined from the cube of the maximum bubble radius coefficient (J) in place of the bubble period coefficient. Ratios of J^3 (for highly aluminized mixtures relative to pentolite) are expected to be somewhat smaller than K^3 for the same mixtures.

One attempt to build and use a bubble probe for the measurement of the maximum bubble radius was successful in 1957. However, the probe could not be used conveniently on a mass production program such as the 1-lb diaphragm gage tests.

Probes for measuring the maximum radius of the explosion bubble were developed by Phillips and Scott (Ref. e). On the tests reported in the main body of this report, one of their bubble probes was used successfully on this 1-lb firing program; i.e., a mass production test. The results obtained are given in this Appendix.

A.2 EXPERIMENTAL TECHNIQUE AND RECORD ANALYSIS

For these tests, a teflon separated probe was rigidly mounted about 27 inches from the center of the charge. The output of the probe was fed through cable to an oscilloscope. The vertical and horizontal sweep of the spot were recorded on a Polaroid Land camera (Ref. e).

The maximum bubble radii, A_{max}, and the bubble periods were read directly from the Polaroid prints*. Values of these measurements are listed in Table A-1 along with the pertinent shot data for each shot. Bubble radius coefficients (J) and bubble period coefficients (K) were calculated by the method outlined in reference (d). Values of the radius coefficient, the period coefficient, ratios of J/K and RBE's (determined for both J^3 and K^3) are shown in Table A-2. The bubble period coefficients are the same values used in the main body of the report to calculate the RBE's. The RBE's are also shown in Figure A-1.

A.3 BUBBLE PERIOD AND RADIUS COEFFICIENT

The radius coefficients for the four weights of pentolite pressed to 95% TMD show a gradual decrease from a value of 13.1 for the 0.5-lb charge to a value of 12.2 for the 1.32-lb charge. The value of 12.6 for

* Bubble periods recorded on rotating drum cameras gave essentially the same values as those recorded on the Polaroid Land cameras.

the 1.0-lb charge is the same as that generally accepted (Ref. h). The values for the charges pressed to 85 and 90% TMD and for the cast pentolite charges are in good agreement with that for the 1.0-lb charge pressed to 95% TMD.

The period coefficients are essentially the same for all of the pentolite charges. The ratio of J/K for the pentolite charges vary from 2.78 to 2.94. These values are in good agreement with previous results.

The ratio of J/K (2.72 to 2.80) for the HBX-1 charges is slightly less than that for pentolite. The values of J obtained herein are slightly lower than the accepted value of 14.4. The ratios of J/K for the TNT/Al/Wax mixtures are nearly the same as those for HBX-1; the values for the AP/TNT/Al mixture are much lower than those for the other explosives.

A.4 RELATIVE BUBBLE ENERGIES

Ratios of J^3 and K^3 (relative to pentolite) are shown in Figure A.1 as a function of % TMD. The J^3 are generally smaller than the K^3; for HBX-1 and TNT/Al/Wax, the differences between J^3 and K^3 become larger with decreasing density; i.e., the charges which detonated high order, give larger differences between RBE's determined by the radius and period constants. In general, lower values for J^3 were predicted; however, the large difference for AP/TNT/Al is much greater than expected.

TABLE A-1

BUBBLE PERIODS AND MAXIMUM BUBBLE RADII
(All shots fired at 9-ft depth)

Explosive	Shot No.	% TMD	Total Chg. Wt. (LBS)	Booster Wt. (LBS)	Water Depth (FT)	Bubble Period (SEC)	Bubble Radius (FT)
Pentolite	B-3384	95	0.500	--	14.5	--	--
	-3408	95	0.500	--	26.0	0.142	2.97
	-3416	95	0.500	--	26.0	0.142	3.00
	-3476	95	0.500	--	26.5	0.145	2.99
Pentolite	B-3392	95	0.661	--	26.0	0.158	3.28
	-3426	95	0.661	--	19.0	0.154	3.23
	-3452	95	0.661	--	26.0	0.158	3.25
	-3484	95	0.661	--	25.5	0.158	3.28
Pentolite	B-3377	95	1.00	--	--	--	--
	-3436	95	1.00	--	19.0	0.175	3.57
	-3460	95	1.00	--	26.0	0.178	3.63
	-3501	95	1.00	--	25.75	0.178	3.68
Pentolite	B-3400	95	1.32	--	25.0	0.191	3.82
	-3444	95	1.32	--	20.0	0.191	3.88
	-3468	95	1.32	--	26.0	0.193	3.88
	-3493	95	1.32	--	25.0	0.192	3.89
Pentolite	B-3381	90.2	1.00	--	14.5	--	--
	-3411	90.2	1.00	--	26.0	0.176	3.58
	-3448	90.2	1.00	--	20.0	0.177	3.58
	-3479	90.2	1.00	--	26.0	0.177	3.59
Pentolite	B-3382	84.2	1.00	--	14.5	--	--
	-3412	84.2	1.00	--	26.0	0.176	3.57
	-3449	84.2	1.00	--	20.0	0.178	3.53
	-3480	84.2	1.00	--	26.0	0.178	3.62
Pentolite (cast)	B-3383	98.6	1.00	--	14.5	--	3.44
	-3413	98.6	1.00	--	26.0	0.177	3.61
	-3450	98.6	1.00	--	20.0	0.176	3.56
	-3481	98.6	1.00	--	25.75	0.178	3.62
HBX-1 (cylindrical booster)	B-3393	97.4	1.00	0.066	26.0	0.189	3.75
	-3430	97.4	1.00	0.066	19.0	0.184	3.69
	-3461	97.4	1.00	0.066	25.0	0.189	3.75
	-3491	97.4	1.00	0.066	25.0	0.187	3.73

TABLE A-1 (continued)

BUBBLE PERIODS AND MAXIMUM BUBBLE RADII

Explosive	Shot No.	% TMD	Total Chg. Wt. (LBS)	Booster Wt. (LBS)	Water Depth (FT)	Bubble Period (SEC)	Bubble Radius (FT)
HBX-1 (cylindrical booster)	B-3394	97.4	1.00	0.220	26.0	0.186	3.71
	-3431	97.4	1.00	0.220	19.0	0.184	3.57
	-3462	97.4	1.00	0.220	25.0	--	3.68
	-3492	97.4	1.00	0.220	25.0	0.186	--
HBX-1	B-3378	97.7	1.00	0.066	14.5	0.191	3.74
	-3414	97.7	1.00	0.066	26.0	0.184	3.75
	-3451	97.7	1.00	0.066	26.0	0.189	3.84
	-3482	97.7	1.00	0.066	25.75	0.187	3.80
HBX-1	B-3385	97.7	1.00	0.220	14.5	0.188	3.68
	-3415	97.7	1.00	0.220	26.0	0.193	3.86
	-3453	97.7	1.00	0.220	26.0	0.191	3.88
	-3483	97.7	1.00	0.220	25.5	0.193	3.95
HBX-1	B-3386	95.8	1.00	0.066	14.5	0.194	3.73
	-3423	95.8	1.00	0.066	19.0	0.195	3.93
	-3454	95.8	1.00	0.066	26.0	0.199	4.00
	-3485	95.8	1.00	0.066	25.25	0.200	4.01
HBX-1	B-3387	95.8	1.00	0.220	14.0	--	--
	-3424	95.8	1.00	0.220	19.0	0.192	3.78
	-3455	95.8	1.00	0.220	26.0	0.194	3.90
	-3486	95.8	1.00	0.220	25.25	0.195	3.91
HBX-1	B-3388	90.3	1.00	0.066	14.0	0.192	3.79
	-3425	90.3	1.00	0.066	19.0	0.195	3.88
	-3456	90.3	1.00	0.066	26.0	0.200	4.03
	-3487	90.3	1.00	0.066	25.0	0.200	3.99
HBX-1	B-3389	90.3	1.00	0.220	14.0	0.193	3.79
	-3427	90.3	1.00	0.220	19.0	0.189	3.83
	-3457	90.3	1.00	0.220	26.0	0.195	3.91
	-3488	90.3	1.00	0.220	25.0	0.197	3.91
HBX-1	B-3390	85.2	1.00	0.066	14.0	0.190	3.73
	-3428	85.2	1.00	0.066	19.0	0.196	3.88
	-3458	85.2	1.00	0.066	26.0	0.201	3.99
	-3489	85.2	1.00	0.066	25.0	0.201	3.98
HBX-1	B-3391	85.2	1.00	0.220	14.0	0.190	3.78
	-3429	85.2	1.00	0.220	19.0	0.193	3.81
	-3459	85.2	1.00	0.220	26.0	0.197	3.91
	-2490	85.2	1.00	0.220	25.0	0.196	3.90

TABLE A-1 (continued)

BUBBLE PERIODS AND MAXIMUM BUBBLE RADII

Explosive	Shot No.	% TMD	Total Chg. Wt. (LBS)	Booster Wt. (LBS)	Water Depth (FT)	Bubble Period (SEC)	Bubble Radius (FT)
HBX-1 (cast)	B-3395	97.7	1.00	0.066	26.0	0.198	3.93
	-3432	97.7	1.00	0.066	19.0	0.198	3.90
	-3463	97.7	1.00	0.066	25.0	0.201	3.99
	-3494	97.7	1.00	0.066	25.0	0.201	3.97
HBX-1 (cast)	B-3396	97.7	1.00	0.220	26.0	0.196	3.90
	-3433	97.7	1.00	0.220	19.0	0.196	3.86
	-3464	97.7	1.00	0.220	26.0	0.195	3.90
	-3495	97.7	1.00	0.220	25.0	0.196	3.88
TNT/Al/Wax 55/40/5	B-3379	95.2	1.00	0.066	14.5	0.157	3.18
	-3397	95.2	1.00	0.066	25.5	0.154	3.29
	-3434	95.2	1.00	0.066	19.0	0.163	3.25
	-3465	95.2	1.00	0.066	26.0	0.162	3.22
TNT/Al/Wax 55/40/5	B-3398	95.2	1.00	0.220	25.5	0.166	3.43
	-3435	95.2	1.00	0.220	19.0	0.168	3.29
	-3466	95.2	1.00	0.220	26.0	0.172	3.27
	-3496	95.2	1.00	0.220	25.0	0.172	3.42
TNT/Al/Wax 55/40/5	B-3399	89.8	1.00	0.066	25.0	0.194	3.83
	-3437	89.8	1.00	0.066	19.0	0.199	3.88
	-3467	89.8	1.00	0.066	26.0	0.204	3.99
	-3497	89.8	1.00	0.066	26.0	0.204	4.08
TNT/Al/Wax 55/40/5	B-3401	89.8	1.00	0.220	25.0	0.200	3.83
	-3438	89.8	1.00	0.220	19.0	0.194	3.78
	-3469	89.8	1.00	0.220	26.0	0.201	3.86
	-3498	89.8	1.00	0.220	26.0	0.199	3.98
TNT/Al/Wax 55/40/5	B-3402	85.1	1.00	0.066	25.0	0.206	4.02
	-3439	85.1	1.00	0.066	19.0	0.205	4.02
	-3470	85.1	1.00	0.066	26.0	0.208	4.08
	-3499	85.1	1.00	0.066	25.75	0.209	4.13
TNT/Al/Wax 55/40/5	B-3403	85.1	1.00	0.220	25.5	0.203	3.93
	-3440	85.1	1.00	0.220	19.0	0.201	3.94
	-3471	85.1	1.00	0.220	26.0	0.206	3.98
	-3500	85.1	1.00	0.220	25.75	0.203	4.02

TABLE A-1 (continued)

BUBBLE PERIODS AND MAXIMUM BUBBLE RADII

Explosive	Shot No.	% TMD	Total Chg. Wt. (LBS)	Booster Wt. (LBS)	Water Depth (FT)	Bubble Period (SEC)	Bubble Radius (FT)
AP/TNT/Al 45/20/35	B-3380	92.3	1.00	0.066	14.5	0.216	3.83
	-3404	92.3	1.00	0.066	25.5	0.222	4.07
	-3441	92.3	1.00	0.066	19.0	0.220	4.04
	-3472	92.3	1.00	0.066	26.0	0.224	4.05
AP/TNT/Al 45/20/35	B-3405	92.3	1.00	0.220	25.5	0.215	3.95
	-3442	92.3	1.00	0.220	20.0	0.215	3.93
	-3473	92.3	1.00	0.220	27.0	0.216	4.12
AP/TNT/Al 45/20/35	B-3406	90.9	1.00	0.066	26.0	0.221	4.03
	-3443	90.9	1.00	0.066	20.0	0.222	4.04
	-3474	90.9	1.00	0.066	26.75	0.223	4.16
	-3502	90.9	1.00	0.066	25.5	0.224	4.20
AP/TNT/Al 45/20/35	B-3407	90.9	1.00	0.220	26.0	0.216	3.98
	-3445	90.9	1.00	0.220	20.0	0.214	3.92
	-3475	90.9	1.00	0.220	26.5	0.217	4.08
AP/TNT/Al 45/20/35	B-3409	84.2	1.00	0.066	26.0	0.223	4.06
	-3446	84.2	1.00	0.066	26.0	0.222	3.96
	-3477	84.2	1.00	0.066	26.25	0.224	4.22
AP/TNT/Al 45/20/35	B-3410	84.2	1.00	0.220	26.0	0.216	3.98
	-3447	84.2	1.00	0.220	20.0	0.215	3.90
	-3478	84.2	1.00	0.220	26.0	0.218	4.08

TABLE A-2

BUBBLE PERIOD AND RADIUS COEFFICIENTS AND RELATIVE BUBBLE ENERGIES

Explosive	Wt. (lb)	% TMD	Radius Coefficient[4] (J) for 30 gm Booster	Radius Coefficient[4] (J) for 100 gm Booster	Radius Coefficient[4] (J) Ave.	Period Coefficient[5] (K) for 30 gm Booster	Period Coefficient[5] (K) for 100 gm Booster	Period Coefficient[5] (K) Ave.	J/K	RBE (pent) J^3	RBE (pent) K^3
Pentolite (P)[1]	0.50	95	--	--	13.1	--	--	4.44	2.94	--	--
	0.66	95	--	--	13.0	--	--	4.45	2.92	--	--
	1.00	95	--	--	12.6	--	--	4.41	2.85	1.00	1.00
	1.32	95	--	--	12.2	--	--	4.40	2.78	--	--
Pentolite (P)	1.00	90.2	--	--	12.4	--	--	4.41	2.82	--	--
	1.00	84.2	--	--	12.4	--	--	4.43	2.80	--	--
Pentolite (C)[2]	1.00	98.6	--	--	12.4	--	--	4.42	2.80	--	--
HBX-1 (P)	1.00	97.7	13.2	13.8	13.5	4.69	4.96	4.83	2.80	1.23	1.30
	1.00	95.8	13.9	13.7	13.8	5.03	4.99	5.01	2.76	1.31	1.45
	1.00	90.3	13.9	13.7	13.8	5.03	4.99	5.01	2.76	1.31	1.45
	1.00	85.2	13.8	13.7	13.8	5.06	5.05	5.06	2.72	1.31	1.50
HBX-1 (C)	1.00	97.7	13.8	13.7	13.8	5.06	5.05	5.06	2.72	1.31	1.50
HBX-1[3] (P)	1.00	97.4	13.0	12.7	12.9	4.71	4.69	4.70	2.74	1.07	1.20
TNT/Al/Wax (P)	1.00	95.2	11.2	11.4	11.3	4.00	4.15	4.08	2.78	0.72	0.79
	1.00	89.8	13.8	13.6	13.7	5.09	5.15	5.12	2.68	1.29	1.56
	1.00	85.1	14.2	14.1	14.2	5.29	5.31	5.30	2.67	1.43	1.72
AP/TNT/Al (P)	1.00	92.3	14.2	14.2	14.2	5.73	5.72	5.73	2.48	1.43	2.17
	1.00	90.9	14.4	14.2	14.3	5.75	5.73	5.74	2.49	1.46	2.18
	1.00	84.2	14.2	14.0	14.1	5.77	5.76	5.77	2.45	1.40	2.22

1. (P) - Pressed charge.
2. (C) - Cast charge.
3. - Pressed charge with pressed cylindrical booster.
4. The units for J are $\frac{ft \cdot ft^{1/3}}{lb^{1/3}}$
5. The units for K are $\frac{sec \cdot ft^{5/6}}{w^{1/3}}$

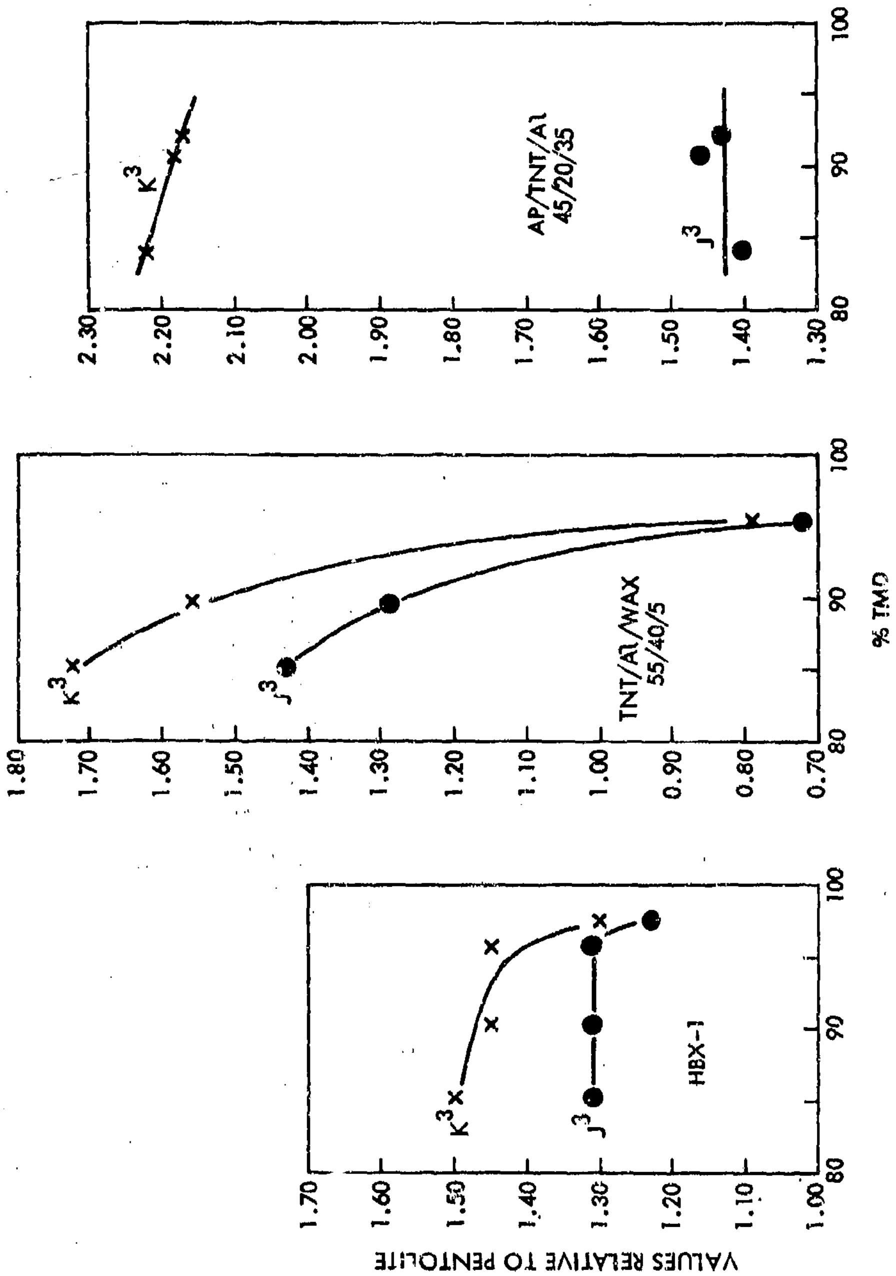


FIG. A-1 RELATIVE BUBBLE ENERGIES (J^3 AND K^3)

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)* U. S. Naval Ordnance Laboratory White Oak, Silver Spring, Maryland 20910	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE
Comparison of the Underwater Power of Explosives in Small Charges
XI. Further Development of Test Procedures

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

5. AUTHOR(S) *(First name, middle initial, last name)*
Thomas B. Heathcote
C. R. Niffenegger

6. REPORT DATE 3 March 1967	7a. TOTAL NO. OF PAGES iii & 20	7b. NO. OF REFS 8

8a. CONTRACT OR GRANT NO. b. PROJECT NO. ORD Task No. ORD-033-211/092-1/F008-08-11 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) NOLTR 67-17 9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*

10. DISTRIBUTION STATEMENT
This document is subject to special export controls and each transmittal to foreign governments may be made only with prior approval of NOL.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Naval Ordnance Systems Command

13. ABSTRACT

Four explosives pressed to three densities and boostered with truncated cones of pressed pentolite were used to continue a study to determine optimum density and boostering for underwater evaluation of small charges. The results show that shock-insensitive mixtures will not fire reliably unless pressed at 90% TMD or less.

Unclassified
Security Classification

Unclassified
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Underwater Explosions						
Boostering						
Bubble radius						
Pentolite						
HBX-1						

DD FORM 1 NOV 65 1473 (BACK)
(PAGE 2)

Unclassified
Security Classification

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